BOILER TRIALS AT THE CHAMPAIGN POWER PLANT OF THE ILLINOIS TRACTION SYSTEM

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

FRANK STANLEY HADFIELD

ENTITLED BOILER TRIALS AT THE CHAMPAIGN POWER PLANT OF THE ILLINOIS TRACTION SYSTEM

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

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BOILER TRIALS AT THE CHAMPAIGN POWER PLANT
OF THE ILLINOIS TRACTION SYSTEM.

The plant at which the following tests were made is located in the northern part of Champaign, Illinois and furnishes current for the Urbana and Champaign Street Railway, for 28 miles of the interurban between Champaign and Danville, Illinois, and also the current for the electric lighting of Champaign.

The boiler equipment consists of a battery of two Stirling boilers rated at 260 horse power each, one Babcock and Wilcox rated at 260 horse power, a battery of two Babcock and Wilcox boilers rated at 150 horse power each, one Aultman and Taylor boiler rated at 150 horse power, and a battery of two Heine boilers rated at 350 horse power each, making a total boiler horse power rating of 1930.

With the exception of the Heine boilers the plant is hand fired throughout. The Heine boilers are equipped with Green Travelling Link Grates.

The boilers are all equipped with natural draft obtained by means of three stadks.

The steam generated is piped into a single main which extends across the engine room and is tapped at various points by mains leading to the different engines.

The coal used is unloaded from a siding in the north side of the boiler house through windows on to the floor of the boiler room in front of the boilers.

The feed water used is pumped from a well by a Cook steam well pump into a tank on the roof of the engine room from which it is pumped as needed into an Excelsior open feed water heater where it is heated by the exhaust steam from the engines up to from 150° to 210° F. From the heater it is pumped by a Blakeslee 14x10x14 boiler feed pump into a 4 inch line from which all the boilers are fed. The ashes are wheeled from in front of the boilers to a chute located about in the center of the boiler room by means of which they are dumped into a car which, when full is hoisted into a tower and automatically dumped into a railway car. It is proposed shortly to build a concrete tunnel in front of all the boilers so that as soon as ashes are drawn out they can be dumped directly into the car and hoisted into the tower.

Purpose.

The purpose of running these tests was to determine just what certain of the boilers were doing in the way of evaporating water with the different coals used.

Three tests were run on the battery of Stirling boilers and a different coal burned each time. One test was run on the large Babcock and Wilcox boiler. Two tests were run on one of the Heine boilers.

TESTS OF THE STIRLING BOILERS.

The Stirling boilers are located in the north-west corner of the boiler room and face east. See plate 1. They are of the type known as class F number 5-1/2. The general dimensions and proportions are given on the log sheet of the tests page 17. See also plate 2.

Draft.

The draft is obtained by a separate steel stack 6 feet indiameter and 150 feet high mounted just above the rear center of the battery and connected to the boilers by sheet iron breechings. Each boiler is fitted with a revolving damper but no regulator is installed and the dampers are not used to regulate the fires.

The boilers are fitted with C. J. Dorrance grates but the rocking attachment is seldom used, the heavy clinker made by the coals used making them very hard to move.

The firing was done by the men usually in charge of the boilers. The blow off valves were tightly closed.

Coal weighing apparatus.

The apparatus for weighihg coal consisted of a Buffalo scale of 1000# capacity fitted wifh a platform large enough to hold an ordinary sheet iron coal barrow. The coal barrow was placed on the scale, balanced, and then loaded with 200 pounds of the coal to be burnt. When the coal was needed the barrow was wheeled in front of the boilers and dumped.

Feed water measuring apparatus.

The feed water was taken from the main line feeding all the boilers through a 2 inch pipe to two galvanized iron measuring tanks placed on a platform. After the tanks were completely filled, they were emptied as needed into a large galvanized iron tank placed under the platform. From this large tank the water was pumped through a "Keystone " 2 inch hot water meter and into the two boilers. (See plate 3)

The two measuring tanks used were carefully calibrated and their exact capacity in pounds of water was known for every temperature of the feed water. The capacities of the tanks are given in table 1 page 13.

The pump used was a Marsh 8"x5"x12" boiler feed pump supplied by steam from the boilers tested.

The height of the water in the lower tank was measured by means of a copper float carrying an iron pointer which moved over a rod graduated in inches.

The overflow from the measuring tanks was carried by a drain pipe to a drain in the floor of the boiler room.

At the point where the main boiler feed line was tapped to supply the measuring tanks another line was put in running directly from the main line through the meter and into the boilers. By means of this line it was possible at any time to determine just what work the boilers were doing, the meter having been calibrated during the tests run.

Steam gauge.

The steam gauge used for determining the pressure was calibrated before using by means of a Crosby gauge tester and was found to be correct for the range of pressures measured.

The thermometers used were new ones purchased from Homan and Mauer and were considered correct.

Method of starting and stopping.

The starting and stopping of the test was according to the alternate method proscribed by the American Society of Mechanical Engineers, Before the start of the test the fires were cleaned and all ash and clinker removed. At the end of the test the fires were again cleaned and left as far as possible in the same condition as at the start.

Coal Sample.

A sample of coal was taken from every wheel barrow just before weighing and placed in a covered can. After the test the sample obtained was carefully mixed then quartered twice and a representative sample placed in a tightly sealed jar and taken to the chemical department of the University of Illinois where it was analyzed. The total per cent of moisture by air drying was also determined by the chemist. The ash sample was obtained in the same manner.

Calorimeter.

The moisture in the steam was determined by means of an improved separating calorimeter manufactured by Schaeffer and Budenbery. The sample of steam for the calorimeter was obtained by means of a preforated pipe inserted in steam line from boiler No. 7. Because of lack of room it was found impossible to get a sample of steam from the vertical pipe attached to the nozzle of the boiler and the sample was taken from the horizontal main as close to the nozzle as convenient.

Flue gas analysis.

The flue gases were analized by means of an Orsat apparatus, a sample being obtained through a preforated pipe inserted in the breeching just behind the damper.

Flue gas temperature.

The flue gas temperature was obtained by a mercury thermometer inserted in the breeching as close to the boiler as possible.

Draft.

The stack draft was taken at the same point by means of a U tube filled with water. The draft over the fire was taken through a hole drilled in the side door opening into the furnace. The readings were taken by students in the University of Illinois every twenty minutes.

Test number 1, Oakwood lump coal.

Test number 1 was made with Oakwood lump coal and an evaporation of 6.63 pounds of water from and at 212° F per pound of dry coal obtained. It was found that the coal used made a very bad clinker due probably to the large amount of iron pyrites as is indicated by the per cent of sulphur.

It was also found that boiler number 7 has a tendency to throw water over when the gage glass is nearly full and also when it contains about one gage of water.

The complete log of the test will be found on page 17.

Test number 2, Odinduff coal.

Test number 2 was made with Odin Duff coal and an evaporation from and at 212° F of 6.24 pounds of water per pound of dry coal obtained. This coal does not seem to be very well adapted to the grates in the Stirling boilers as it is so fine a large amount drops through into the ashpit as is shown by the ash analysis which gave 48.83% car bon. It will also be noticed by the log sheet page that the horse power developed was considerably below rating showing that the coal is not adapted to heavy firing.

Test number 3, Oakwood screenings.

Test number 3 was made with Oakwood screenings, an evaporation of 6.85 pounds of water from and at 212° F per pound of dry coal being obtained. This was the best result obtained in the tests of the Stirlings, and the increase in evaperation is due most likely to the better combustion of the coal as shown by the flue gas analysis. The better fire is due probably to the size of the coal and also to the care taken by the fireman to keep a level fire entirely free from holes.

The complete log of the test will be found on page.17.

Test of the Babcock and Wilcox boiler.

The Babcock and Wilcox boiler tested is located at the west end of the line of boilers running east and west and faces north. See plate No. 1. It obtains its draft from a brick stack 8 feet in diameter and 125 feet high located about the center of the boiler house. It is connected to the stack by a brick breeching running slong the rear of the row of boilers.

The boiler is an old style boiler having 30" drums. It is equipped with three fire doors and the ordinary style st straight grate bars. See plate 4. It is supplied with a sliding sheet iron damper but it is not used to regulate the fire.

The firing was done by the regular fireman. The apparatus for weighing coal was the same as that used on the Stirling tests. The water measuring apparatus did not have to be moved to test this boiler only a slight change in the piping being necessary. The apparatus used in the other tests for general readings was used in this test.

Flue gas temperature .

The flue gas temperature was taken through a hole in the breeching just behind the damper. The rear draft was also taken at this point.

Flue gas sample.

The flue gas sample was drawn through a preforated pipe inserted through another hole in the breeching and so arranged as to get a fair sample of the gas.

Calorimeter.

The calorimeter was attached to the center one of the three nozzles on the boiler, the calorimeter used being the same one as used on the Stirling boilers.

Test number 4 , Oakwood screenings.

This test of the Babcock and Wilcox boiler was made with Oakwood screenings and as will be noticed by the log sheet page an evaporation of only 5.02 pounds of water from and at 212° F. per pound of dry coal was obtained.

The causes of this low evaporation can be outlined as follows:-

1. The large (7.8) per cent of moisture in the steam generated. There was no apparent reason for this as at times the steam would be practically dry and at other times with the water level the same as much as 15% moisture would be observed.

2. The poor condition of the brickwork in the furnace, a large number of the fire-brick in the side wall having fallen out, and finally 3. The looseness of the boiler setting itself causing considerable leakage of air.

It will be noticed by the log sheet page 18 that only 64 per cent of the boiler rating was developed on this test although the boiler was worked as hard as possible throughout the test. The low result is due largely to the lack of draft .4 of an inch of water being the highest reading recorded during the test. With this low draft it was impossible to burn the coal rapidly enough to develop the horse power rating of the boiler.

The low draft observed was due to the large amount of soot and ash in the breeching, to the overloading of the stack, and to leaks in the breeching.

TESTS OF THE HEINE BOILER.

The Heine boiler tested is located at the east end of the east and west row of boilers and is the second one of the battery of two. See plates 1 and 5.

The battery has just been installed in the plant having been bought from the St. Louis World's Fair.

They are equipped with new Green Travelling Link grates with the Herington patent movable water back attachment. The stokers are driven by a two horse power steam engine placed above and to one side of the battery.

The cooling water used in the water backs is furnished by the supply tank on the roof of the engine room. After going through the water backs it is drawn into the pump room by means of a small duplex pump and forced into the feed water heater.

Draft.

The draft for the battery is obtained from a separate steel stack erected just outside the south wall of the building and directly behind the two boilers. The stack is 7 feet in diameter, 150 feet high and is lined 1/3 the way up with fire brick.

The apparatus used in these tests of the Heine boiler was the same as used on the tests of the other boilers.

Water measuring apparatus.

The water measuring apparatus had to be moved close to the boilers and the piping arrangement was somewhat different than that used before. (See photograph page 16.)

Instead of using the water from the heater as before cold water from the city mains was used on these tests. This change was made because at the time of year (May) the tests were made very little of the exhaust steam from the engines is used in the city heating system and consequently the water in the heater is raised to a higher temperature than is the case in the colder months. It was found when testing the Babcock and Wilcox boiler that it was almost impossible to measure this feed water of such high temperature (200° and over) accurately in the measuring tanks used so it was decided in the interests of accuracy to use cold water in any further tests to be run.

As before the water after being measured in the calibrated tanks was emptied as needed into the large tank placed below them and from there pumped into the boiler. (See photograph page 15.)

At the start of the test all ash and coal was removed from under the grates and the coal hopper filled level full with coal.

At the end of the test the ash was drawn out and weighed and the coal hopper again filled level full with weighed coal.

The flue gas temperature was taken through a hole in the

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breeching just behind t he boilers. The rear draft was taken at the same point. The draft over the fire was taken through the peep hole in the small observation door in the side of the furnace.

The calorimeter was attached to the vertical steam main just above the boiler.

The same thickness of fire was maintained throughout the test, the combustion being regulated by the speed of the stoker. The damper in the breeching was wide open throughout the test. The blow off valve was tight.

Test number 5. Oakwood screenings.

Test number 5, the first test of the Heine boiler was run with Oakwood screenings.

The stoker was run by Frank Henderson, erector for the Green Engineering Co, who was present in the interests of the stoker Company. As will be noticed by the log sheet page , the horse poweredeveloped by the boiler was considerable above rating while at the same time the equivalent evaporation from and at 212 $^\circ$F per pound of dry coal was not in any way remarkable. The only reason that can be given for this under the circumstance s is the excessive overloading of the boiler. This reasoning is borne out somewhat by the high temperature of the flue gases.

Attention should also be called to the excellent flue gas analysis obtained which if compared with the results obtained on the hand fired boilers show conclusively the better combustion that can be obtained by the use of stokers.

Test number 6. Oakwood screenings.

In order to see just what the boiler tested above would do when working about normally another test was run on it with the same kind of coal.

The results of the tests appear on page 19 .

Conclusions.

The results obtained from the above tests show the following.

1. As was to be expected the stoker is considerably more efficient than hand fire and under the conditions surrounding this plant can be forced more than the hand fired furnace.

2. With the exception of the Heine boiler the boilers tested were none in first class shape due to the fact that during the winter before the Heine boilers were erected, it was impossible to shut down a boiler long enough to make any extensive repairs and still handle the load.

3. Of the three kinds of coal tested, the Oakwood screenings seems to be the best adapted and it is desirable that this coal be supplied continuously to all the boilers.

The policy pursued at this plant of using three different sizes and grades of coal on the same boiler sometimes on the same day while perhaps necessary under the present system of coal supply is very detrimental to efficient evaporation.

4. It seems possible, however, now that enough boilers are installed to allow the cutting out of one for repairs to bring the plant as a whole up to a much more economical condition than it was found to be in when tested.

CAPACITY OF MEASURING TANKS

Temp. of Water	Capacity Tank No1	Capacity Tank No2
55°	$1120\frac{1}{4}$ lbs.	$1127\frac{1}{2}$ lbs.
100°	$1113\frac{1}{2}$ "	$1120\frac{3}{4}$ "
120°	$1108\frac{1}{2}$ "	1115.7 "
140°	1101.9 "	1109 "
160°	1094.9 "	1102 "
180°	10872 "	1094.2 "
200°	10786 "	$1085\frac{1}{2}$ "
210°	1074 "	1081 "


B&W.
260 FP.
Stirlings


HEINE BOILER

1—04—1000R

UNIVERSITY OF ILLINOIS,

MECHANICAL ENGINEERING LABORATORY.

RESULTS OF BOILER TRIAL

Tets number: #1 #2 #3

Made by: F.S. Hadfield

At: The Urbana + Champaign St. Ry. Power Plant

Kind of boiler (Commercial name). Stirling

To determine: Evaporation under ordinary conditions

Principal conditions governing trial: 2 Boilers; Hot feed water; Ordinary loading

Kind of fuel: Illinois coal

Kind of furnace: C.J. Dorrance

No.	Item	#1	#2	#3
	State of the weather	Fair	Cloudy	Rain
	Method of starting and stopping the test	A.S.M.E. Alternate method.		
	Number of boiler (Plant number).	7+8		
	Type of boiler	Water tube		
1.	*Date of trial*	Mar. 10, '05	Mar. 28, '05	Apr. 25, '05
2.	*Duration of trial*	24 hrs.	23h. 37m.	10h. 48m.

DIMENSIONS AND PROPORTIONS.

Each Boiler

No.	Item	Each Boiler
3.	*Grate surface, square feet,*	50.9
3.1	*Width of grate, feet,*	7'-6"
3.2	*Length of grate, feet,*	6'-9½"
4.	Height of furnace, inches,	
5.	Approximate width of air spaces in grate, inches,	
6.	Proportion of air space to whole grate surface, per cent.,	
6.1	Area of chimney, square feet,	28.27
6.2	Height of chimney above grate, feet,	150
6.3	Length of flue connecting to chimney, feet,	
6.4	Kind of draft,	Natural
7.	*Water heating surface, square feet,*	2,587
7.1	Outside diameter of shell, inches,	42"
7.2	Length of shell (outside to outside of heads), feet,	10'-4"
7.3	Number of tubes,	219
7.4	Diameter of tubes (outside—~~inside~~), inches,	3¼"
7.5	Length of tubes, feet,	15'
8.	*Superheating surface, square feet*	
9.	Ratio of water heating surface to grate surface, — to 1.	50.8
10.	Ratio of minimum draft area to grate surface, 1 to —.	

AVERAGE PRESSURES.

No.	Item	#1	#2	#3
11.	*Steam pressure by gauge, lbs. per square inch,*	112.3	110.6	110.7
12.	*Force of draft between damper and boiler, inches of water,*	.79	.65	.79
13.	Force of draft in furnace, inches of water,	.54	.275	.365
14.	Force of draft or blast in ashpit, inches of water,	.2	.1	.15

AVERAGE TEMPERATURES.

No.	Item	#1	#2	#3
15.	Of external air, degrees,	32.1	44	58.5
16.	Of fireroom, degrees,	38	59	71.3
17.	Of steam, degrees,			
18.	Of feed water entering heater, degrees,			
19.	Of feed water entering economizer, degrees,			
20.	*Of feed water entering boiler, degrees,*	182.8	178.5	200
21.	*Of escaping gases from boiler, degrees,*	633.6	591	615.6
22.	Of escaping gases from economizer, degrees,			

FUEL.

No.	Item	#1	#2	#3
23.	Size and condition	Lump	Duff	Screenings 70% fine
	TEST NUMBER	#1	#2	#3
24.	Weight of wood used in lighting fire, lbs.,			
25.	*Weight of coal as fired, lbs.,*	66650	53800	29990
26.	*Percentage of moisture in coal, per cent.,*	6.8	7.21	8.01
27.	*Total weight of dry coal consumed, lbs.,*	62118	49921	27588
28.	*Total ash and refuse, lbs.,*	11066	11504	5057
29.	Quality of ash and refuse,			
30.	Total combustible consumed, lbs.,	51052	38417	22531
31.	*Percentage of ash and refuse in dry coal, per cent.,*			

PROXIMATE ANALYSIS OF COAL.

No.	Item	#1 Per Cent of Coal.	#1 Per Cent of Combust'e	#2 Per Cent of Coal.	#2 Per Cent of Combust'e	#3 Per Cent of Coal.	#3 Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'le
32.	Fixed carbon,	45.13		45.14		42.19			
33.	Volatile matter,	37.40		31.79		35.55			
34.	Moisture,	6.8		7.21		8.24			
35.	Ash,	10.67		15.86		14.02			
		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
36.	Sulphur, separately determined,	3.4		2.12		3.23			

ULTIMATE ANALYSIS OF DRY COAL.

No.	Item	#1 Per Cent of Coal.	#1 Per Cent of Combust'e	#2 Per Cent of Coal.	#2 Per Cent of Combust'e	#3 Per Cent of Coal.	#3 Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'le
37.	Carbon (C),								
38.	Hydrogen (H),								
39.	Oxygen (O),								
40.	Nitrogen (N),								
41.	Sulphur (S),								
42.	Ash,								
43.	Moisture in sample of coal as received,								
		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

ANALYSIS OF ASH AND REFUSE.

No.	Item	#1	#2	#3
44.	Carbon, per cent.	16.94	48.83	8.01
45.	Earthy matter, per cent.			

FUEL PER HOUR.

No.	Item	#1	#2	#3
46.	*Dry coal consumed per hour, lbs.,*	2588	2114	2554
47.	Combustible consumed per hour, lbs.,	2127	1627	2086
48.	*Dry coal per square foot of grate surface per hour, lbs.,*	25.4	20.7	25.0
49.	Combustible per square foot of water-heating surface per hour, lbs.,	.41	.314	.403

CALORIFIC VALUE OF FUEL.

No.	Item	#1	#2	#3
50.	*Calorific value by oxygen calorimeter, per lb. of dry coal, B.T.U.*	12503	11185	11427
51.	*Calorific value by oxygen calorimeter per lb. of combustible, B.T.U.*	13966	13293	13279
52.	Calorific value by analysis, per lb. of dry coal, B.T.U.			
53.	Calorific value by analysis, per lb. of combustible, B.T.U.			

QUALITY OF STEAM.

No.	Item	#1	#2	#3
54.	*Percentage of moisture in steam, per cent.,*	1.1%	.76%	7.6%
55.	*Number of degrees of superheating, degrees,*			
56.	Quality of steam (dry steam = unity).	.989	.9924	.9924

WATER.

No.	Item	#1	#2	#3
57.	*Total weight of water fed to boiler, lbs.,*	389247	292473	180762
58.	Equivalent water fed to boiler from and at 212 degrees, lbs.,	416494	314116	190523
59.	*Water actually evaporated, corrected for quality of steam, lbs.,*	384965	290250	179388
60.	Factor of evaporation,	1.070	1.074	1.054
61.	Equivalent water evaporated into dry steam from and at 212 degrees, (Item 59 × Item 60), lbs.	411989	311728	189075

WATER PER HOUR.

No.	Item	#1	#2	#3
62.	*Water evaporated per hour, corrected for quality of steam, lbs.,*	16040	12290	16610
63.	*Equivalent evaporation per hour from and at 212 degrees, lbs.,*	17166	13200	17507
64.	*Equivalent evaporation per hour from and at 212 degrees per square foot of water-heating surface, lbs.,*	3.31	2.55	3.38

HORSE-POWER.

No.	Item	#1	#2	#3
65.	*Horse-power developed. (34½ lbs. of water evaporated per hour into dry steam from and at 212 degrees, equals one horse-power), H.P.,*	497.5	382.6	507.4
	TEST NUMBER.	#1	#2	#3
66.	*Builders' rated horse-power, H.P.,*	520	520	520
67.	*Percentage of builders' rated horse-power developed, per cent.,*	95.8	73.5	97.5

ECONOMIC RESULTS.

No.	Item	#1	#2	#3
68.	*Water apparently evaporated under actual conditions per pound of coal as fired. (Item 57 ÷ Item 25), lbs.,*	5.84	5.43	6.02
69.	*Equivalent evaporation from and at 212 degrees per pound of coal as fired. (Item 61 ÷ Item 25), lbs.,*	6.18	5.79	6.34
70.	*Equivalent evaporation from and at 212 degrees per pound of dry coal. (Item 61 ÷ Item 27), lbs.,*	6.63	6.24	6.85
71.	*Equivalent evaporation from and at 212 degrees per pound of combustible. (Item 61 ÷ Item 30), lbs.,* (If the equivalent evaporation, Items 69, 70 and 71, is not corrected for the quality of steam, the fact should be stated.)	8.07	8.11	8.30

EFFICIENCY.

No.	Item	#1	#2	#3
72.	*Efficiency of the boiler; heat absorbed by the boiler per lb. of combustible divided by the heat value of one lb. of combustible, per cent.,*	55.8	58.8	60.3
73.	*Efficiency of boiler, including the grate; heat absorbed by the boiler, per lb. of dry coal, divided by the heat value of one lb. of dry coal, per cent.,*	51.0	53.8	57.9

COST OF EVAPORATION.

No.	Item	#1	#2	#3
74.	*Cost of coal per ton of 2000 lbs. delivered in boiler room, $*	2.10	.75	.95
75.	Cost of fuel for evaporating 1,000 lbs. of water under observed conditions, $	.179	.069	.078
76.	*Cost of fuel used for evaporating 1,000 lbs. of water from and at 212 degrees, $*	.169	.064	.075

SMOKE OBSERVATIONS.

No.	Item	#1	#2	#3
77.	Percentage of smoke as observed, per cent.,			
78.	Weight of soot per hour obtained from smoke meter, ounces,			
79.	Volume of soot per hour obtained from smoke meter, cub. in.			

METHODS OF FIRING.

No.	Item	#1	#2	#3
80.	Kind of firing (spreading, alternate, or coking).	Spreading		
81.	Average thickness of fire.	6"	7½"	7"
82.	Average intervals between firing for each furnace during time when fires are in normal condition.			
83.	Average interval between times of leveling or breaking up.			

ANALYSIS OF THE DRY GASES.

No.	Item	#1	#2	#3
84.	Carbon dioxide (CO_2), per cent.,	2.7	4.82	5.48
85.	Oxygen (O), per cent.,	16.57	14.39	14.07
86.	Carbon monoxide (CO), per cent.,	.4	.5	.15
87.	Hydrogen and hydrocarbons, per cent.,			
88.	Nitrogen (by difference) (N), per cent.,	80.33	80.28	80.30

HEAT BALANCE, OR DISTRIBUTION OF THE HEATING VALUE OF THE COMBUSTIBLE.

Total Heat Value of 1 lb. of Combustible, B.T.U.

No.	Item	B.T.U.	Per Cent.	B.T.U.	Per Cent.	B.T.U.	Per Cent.	B.T.U.	Per Cent.
1.	Heat absorbed by the boiler = evaporation from and at 212 degrees per pound of combustible × 965.7.								
2.	Loss due to moisture in coal = per cent. of moisture referred to combustible ÷ 100 × $[(212 - t) + 966 + 0.48\ (T - 212)]$ (t = temperature of air in the boiler-room, T = that of the flue gases)								
3.	Loss due to moisture formed by the burning of hydrogen = per cent. of hydrogen to combustible ÷ 100 × 9 × $[(212 - t) + 966 + 0.48\ (T - 212)]$.								
4.	Loss due to heat carried away in the dry chimney gases = weight of gas per pound of combustible × 0.24 × $(T - t)$.								
5.	Loss due to incomplete combustion of carbon = $\frac{CO}{CO_2 + CO} \times \frac{\text{per cent. C in combustible}}{100} \times 10{,}150$.								
6.	Loss due to unconsumed hydrogen and hydrocarbons, to heating the moisture in the air, to radiation, and unaccounted for. (Some of these losses may be separately itemized if data are obtained from which they may be calculated.)								
	Totals.		100.00		100.00		100.00		100.00

UNIVERSITY OF ILLINOIS,

MECHANICAL ENGINEERING LABORATORY.

RESULTS OF BOILER TRIAL

Test number		#4
Made by		F. S. Hadfield
At		Urbana + Champaign St. Ry. Power Plant
Kind of boiler (Commercial name).		Babcock + Wilcox
To determine		Evaporation under ordinary conditions
Principal conditions governing trial		Hot feed water Ordinary loading
Kind of fuel		Illinois coal
Kind of furnace		
State of the weather		Rain
Method of starting and stopping the test		A.S.M.E. Alternate method
Number of boiler (Plant number)		6
Type of boiler		Water tube
1.	Date of trial	Apr. 28, '05
2.	Duration of trial	10 h. 20 m.

DIMENSIONS AND PROPORTIONS.

3.	Grate surface, square feet,	64
3.1	Width of grate, feet,	10'-9"
3.2	Length of grate, feet,	6'-0"
4.	Height of furnace, inches,	
5.	Approximate width of air spaces in grate, inches,	
6.	Proportion of air space to whole grate surface, per cent.,	
6.1	Area of chimney, square feet,	50.26
6.2	Height of chimney above grate, feet,	125'
6.3	Length of flue connecting to chimney, feet,	
6.4	Kind of draft,	Natural
7.	Water heating surface, square feet,	2860
7.1	Outside diameter of shell, inches,	30"
7.2	Length of shell (outside to outside of heads), feet,	16'-5"
7.3	Number of tubes,	126
7.4	Diameter of tubes (outside—~~inside~~), inches,	4"
7.5	Length of tubes, feet,	15'-7"
8.	Superheating surface, square feet	
9.	Ratio of water heating surface to grate surface, 44.7 to 1.	
10.	Ratio of minimum draft area to grate surface, 1 to —.	

AVERAGE PRESSURES.

11.	Steam pressure by gauge, lbs. per square inch,	102
12.	Force of draft between damper and boiler, inches of water,	.33
13.	Force of draft in furnace, inches of water,	.178
14.	Force of draft or blast in ashpit, inches of water,	

AVERAGE TEMPERATURES.

15.	Of external air, degrees,	72.6
16.	Of fireroom, degrees,	90.4
17.	Of steam, degrees,	
18.	Of feed water entering heater, degrees,	
19.	Of feed water entering economizer, degrees,	
20.	Of feed water entering boiler, degrees,	178
21.	Of escaping gases from boiler, degrees,	564.5
22.	Of escaping gases from economizer, degrees,	

FUEL.

23.	Size and condition	Screenings

TEST NUMBER		#4
24.	Weight of wood used in lighting fire, lbs.,	
25.	Weight of coal as fired, lbs.,	12600
26.	Percentage of moisture in coal, per cent.,	6.02%
27.	Total weight of dry coal consumed, lbs.,	11841
28.	Total ash and refuse, lbs.,	2815
29.	Quality of ash and refuse,	
30.	Total combustible consumed, lbs.,	9026
31.	Percentage of ash and refuse in dry coal, per cent.,	

PROXIMATE ANALYSIS OF COAL.

		Per Cent of Coal.	Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'e
32.	Fixed carbon,	38.88							
33.	Volatile matter,	33.43							
34.	Moisture,	6.02							
35.	Ash,	21.67							
		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
36.	Sulphur, separately determined,	3.21							

ULTIMATE ANALYSIS OF DRY COAL.

		Per Cent of Coal.	Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'e
37.	Carbon (C),								
38.	Hydrogen (H),								
39.	Oxygen (O),								
40.	Nitrogen (N),								
41.	Sulphur (S),								
42.	Ash,								
43.	Moisture in sample of coal as received,								
		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

ANALYSIS OF ASH AND REFUSE.

44.	Carbon, per cent.	16.93
45.	Earthy matter, per cent.	

FUEL PER HOUR.

46.	Dry coal consumed per hour, lbs.,	1146
47.	Combustible consumed per hour, lbs.,	874
48.	Dry coal per square foot of grate surface per hour, lbs.,	17.9
49.	Combustible per square foot of water-heating surface per hour, lbs.,	.30

CALORIFIC VALUE OF FUEL.

50.	Calorific value by oxygen calorimeter, per lb. of dry coal, B.T.U.	10299.3
51.	Calorific value by oxygen calorimeter per lb. of combustible, B.T.U.	13226
52.	Calorific value by analysis, per lb. of dry coal, B.T.U.	
53.	Calorific value by analysis, per lb. of combustible, B.T.U.	

QUALITY OF STEAM.

54.	Percentage of moisture in steam, per cent.,	7.8%
55.	Number of degrees of superheating, degrees,	
56.	Quality of steam (dry steam = unity).	.922

WATER.

57.	Total weight of water fed to boiler, lbs.,	60015
58.	Equivalent water fed to boiler from and at 212 degrees, lbs.,	64516
59.	Water actually evaporated, corrected for quality of steam, lbs.,	55334
60.	Factor of evaporation,	1.075
61.	Equivalent water evaporated into dry steam from and at 212 degrees, (Item 59 × Item 60), lbs.	59484

WATER PER HOUR.

62.	Water evaporated per hour, corrected for quality of steam, lbs.,	5356
63.	Equivalent evaporation per hour from and at 212 degrees, lbs.,	5758
64.	Equivalent evaporation per hour from and at 212 degrees per square foot of water-heating surface, lbs.,	2.01

HORSE-POWER.

65.	Horse-power developed. (34½ lbs. of water evaporated per hour into dry steam from and at 212 degrees, equals one horse-power), H.P.,	166.8

TEST NUMBER		#4
66.	Builders' rated horse-power, H.P.,	260
67.	Percentage of builders' rated horse-power developed, per cent.,	64.1

ECONOMIC RESULTS.

68.	Water apparently evaporated under actual conditions per pound of coal as fired. (Item 57 ÷ Item 25), lbs.,	4.76
69.	Equivalent evaporation from and at 212 degrees per pound of coal as fired. (Item 61 ÷ Item 25), lbs.,	4.71
70.	Equivalent evaporation from and at 212 degrees per pound of dry coal. (Item 61 ÷ Item 27), lbs.,	5.02
71.	Equivalent evaporation from and at 212 degrees per pound of combustible. (Item 61 ÷ Item 30), lbs., (If the equivalent evaporation, Items 69, 70 and 71, is not corrected for the quality of steam, the fact should be stated.)	6.59

EFFICIENCY.

72.	Efficiency of the boiler; heat absorbed by the boiler per lb. of combustible divided by the heat value of one lb. of combustible, per cent.,	48.1
73.	Efficiency of boiler, including the grate; heat absorbed by the boiler, per lb. of dry coal, divided by the heat value of one lb. of dry coal, per cent.,	47

COST OF EVAPORATION.

74.	Cost of coal per ton of 2240 lbs. delivered in boiler room, $	.95
75.	Cost of fuel for evaporating 1,000 lbs. of water under observed conditions, $	.10
76.	Cost of fuel used for evaporating 1,000 lbs. of water from and at 212 degrees, $	.1007

SMOKE OBSERVATIONS.

77.	Percentage of smoke as observed, per cent.,	
78.	Weight of soot per hour obtained from smoke meter, ounces,	
79.	Volume of soot per hour obtained from smoke meter, cub. in.	

METHODS OF FIRING.

80.	Kind of firing (spreading, alternate, or coking).	Spreading
81.	Average thickness of fire.	6"
82.	Average intervals between firing for each furnace during time when fires are in normal condition.	
83.	Average interval between times of leveling or breaking up.	

ANALYSIS OF THE DRY GASES.

84.	Carbon dioxide (CO_2), per cent.,	4.7
85.	Oxygen (O), per cent.,	14.6
86.	Carbon monoxide (CO), per cent.,	.3
87.	Hydrogen and hydrocarbons, per cent.,	
88.	Nitrogen (by difference) (N), per cent.,	80.4

HEAT BALANCE, OR DISTRIBUTION OF THE HEATING VALUE OF THE COMBUSTIBLE.

Total Heat Value of 1 lb. of Combustible, B.T.U.

		B.T.U.	Per Cent.	B.T.U.	Per Cent.	B.T.U.	Per Cent.	B.T.U.	Per Cent.
1.	Heat absorbed by the boiler = evaporation from and at 212 degrees per pound of combustible × 965.7.								
2.	Loss due to moisture in coal = per cent. of moisture referred to combustible ÷ 100 × [(212 − t) + 966 + 0.48 (T − 212)] (t = temperature of air in the boiler-room, T = that of the flue gases)								
3.	Loss due to moisture formed by the burning of hydrogen = per cent. of hydrogen to combustible ÷ 100 × 9 × [(212 − t) + 966 + 0.48 (T − 212)].								
4.	Loss due to heat carried away in the dry chimney gases = weight of gas per pound of combustible × 0.24 × (T − t).								
5.	Loss due to incomplete combustion of carbon = $\frac{CO}{CO_2 + CO} \times \frac{\text{per cent. C in combustible}}{100} \times 10,150$.								
6.	Loss due to unconsumed hydrogen and hydrocarbons, to heating the moisture in the air, to radiation, and unaccounted for. (Some of these losses may be separately itemized if data are obtained from which they may be calculated.)								
	Totals.		100.00		100.00		100.00		100.00

1-04-1000

UNIVERSITY OF ILLINOIS,
MECHANICAL ENGINEERING LABORATORY.
RESULTS OF BOILER TRIAL

		#5	#6
Test number			
Made by	F.S. Hadfield		
At	Champaign & Urbana St. Ry. Power Plant		
Kind of boiler (Commercial name).	Heine		
To determine	Evaporation per lb. of coal and horse power		
Principal conditions governing trial	Cold feed water		
Kind of fuel	Illinois coal		
Kind of furnace	Green Chain Grate		
State of the weather		Fair	Rain
Method of starting and stopping the test	A.S.M.E. Alternate method		
Number of boiler (Plant number).			
Type of boiler	Water R tube		
1. Date of trial		May 12, '05	May 25, '05
2. Duration of trial		5 hrs.	11 h. 4 m.

DIMENSIONS AND PROPORTIONS.

No.	Item	Value
3.	Grate surface, square feet,	72
3.1	Width of grate, feet,	8'-0"
3.2	Length of grate, feet,	9'-0"
4.	Height of furnace, inches,	
5.	Approximate width of air-spaces in grate, inches,	
6.	Proportion of air space to whole grate surface, per cent.,	
6.1	Area of chimney, square feet,	38.48
6.2	Height of chimney above grate, feet,	150'
6.3	Length of flue connecting to chimney, feet,	
6.4	Kind of draft,	Natural
7.	Water heating surface, square feet,	3160
7.1	Outside diameter of shell, inches,	48"
7.2	Length of shell (outside to outside of heads), feet,	21'-3¼"
7.3	Number of tubes,	176
7.4	Diameter of tubes (outside—~~inside~~), inches,	3½"
7.5	Length of tubes, feet,	18'
8.	Superheating surface, square feet	
9.	Ratio of water heating surface to grate surface, — to 1.	43.9
10.	Ratio of minimum draft area to grate surface, 1 to —	

No.	Item	#5	#6
	AVERAGE PRESSURES.		
11.	Steam pressure by gauge, lbs. per square inch,	118	105.8
12.	Force of draft between damper and boiler, inches of water,	.81	.6
13.	Force of draft in furnace, inches of water,	.256	.125
14.	Force of draft or blast in ashpit, inches of water,		
	AVERAGE TEMPERATURES.		
15.	Of external air, degrees,	70.8	67
16.	Of fireroom, degrees,	68.7	76
17.	Of steam, degrees,		
18.	Of feed water entering heater, degrees,		
19.	Of feed water entering economizer, degrees,		
20.	Of feed water entering boiler, degrees,	63	64
21.	Of escaping gases from boiler, degrees,	637	546
22.	Of escaping gases from economizer, degrees,		
	FUEL.		
23.	Size and condition	Screenings	Screenings

No.	TEST NUMBER	#5	#6
24.	Weight of wood used in lighting fire, lbs.,		
25.	Weight of coal as fired, lbs.,	12400	17800
26.	Percentage of moisture in coal, per cent.,	6.08	9.87
27.	Total weight of dry coal consumed, lbs.,	11646	16043
28.	Total ash and refuse, lbs.,	2708	3982
29.	~~Quality~~ 410/57. of ash and refuse, %	.58%	
30.	Total combustible consumed, lbs.,	8954	12061
31.	Percentage of ash and refuse in dry coal, per cent.,		

PROXIMATE ANALYSIS OF COAL.

No.	Item	Per Cent of Coal.	Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'e
32.	Fixed carbon,	41.76							
33.	Volatile matter,	35.25							
34.	Moisture,	6.08							
35.	Ash,	16.91							
		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
36.	Sulphur, separately determined,	3.14							

ULTIMATE ANALYSIS OF DRY COAL.

No.	Item	Per Cent of Coal.	Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'e	Per Cent of Coal.	Per Cent of Combust'e
37.	Carbon (C),								
38.	Hydrogen (H),								
39.	Oxygen (O),								
40.	Nitrogen (N),								
41.	Sulphur (S),								
42.	Ash,								
43.	Moisture in sample of coal as received,								
		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

No.	Item	#5	#6
	ANALYSIS OF ASH AND REFUSE.		
44.	Carbon, per cent.	17.38	20.79
45.	Earthy matter, per cent.		
	FUEL PER HOUR.		
46.	Dry coal consumed per hour, lbs.,	2329	1450
47.	Combustible consumed per hour, lbs.,	1791	1090
48.	Dry coal per square foot of grate surface per hour, lbs.,	32.3	20.1
49.	Combustible per square foot of water-heating surface per hour, lbs.,	.56	.34
	CALORIFIC VALUE OF FUEL.		
50.	Calorific value by oxygen calorimeter, per lb. of dry coal, B.T.U.	10980	11154
51.	Calorific value by oxygen calorimeter per lb. of combustible, B.T.U.	13214	12747
52.	Calorific value by analysis, per lb. of dry coal, B.T.U.		
53.	Calorific value by analysis, per lb. of combustible, B.T.U.		
	QUALITY OF STEAM.		
54.	Percentage of moisture in steam, per cent.,	.65%	.36%
55.	Number of degrees of superheating, degrees,		
56.	Quality of steam (dry steam = unity).	.9935	.9964
	WATER.		
57.	Total weight of water fed to boiler, lbs.,	66630	98025
58.	Equivalent water fed to boiler from and at 212 degrees, lbs.,	79823	117042
59.	Water actually evaporated, corrected for quality of steam, lbs.,	66197	97672
60.	Factor of evaporation,	1.198	1.194
61.	Equivalent water evaporated into dry steam from and at 212 degrees, (Item 59 × Item 60), lbs.	79304	116620
	WATER PER HOUR.		
62.	Water evaporated per hour, corrected for quality of steam, lbs.,	13239	8831
63.	Equivalent evaporation per hour from and at 212 degrees, lbs.,	15861	10544
64.	Equivalent evaporation per hour from and at 212 degrees per square foot of water-heating surface, lbs.,	5.01	3.33
	HORSE-POWER.		
65.	Horse-power developed. (34½ lbs. of water evaporated per hour into dry steam from and at 212 degrees, equals one horse-power), H.P.,	459.7	305.6

No.	TEST NUMBER	#5	#6
66.	Builders' rated horse-power, H.P.,	350	350
67.	Percentage of builders' rated horse-power developed, per cent.,	131.3%	87%
	ECONOMIC RESULTS.		
68.	Water apparently evaporated under actual conditions per pound of coal as fired. (Item 57 ÷ Item 25), lbs.,	5.37	5.50
69.	Equivalent evaporation from and at 212 degrees per pound of coal as fired. (Item 61 ÷ Item 25), lbs.,	6.39	6.55
70.	Equivalent evaporation from and at 212 degrees per pound of dry coal, (Item 61 ÷ Item 27), lbs.,	6.80	7.26
71.	Equivalent evaporation from and at 212 degrees per pound of combustible. (Item 61 ÷ Item 30), lbs., (If the equivalent evaporation, Items 69, 70 and 71, is not corrected for the quality of steam, the fact should be stated.)	8.85	9.67
	EFFICIENCY.		
72.	Efficiency of the boiler; heat absorbed by the boiler per lb. of combustible divided by the heat value of one lb. of combustible, per cent.,	64.7	73.2
73.	Efficiency of boiler, including the grate; heat absorbed by the boiler, per lb. of dry coal, divided by the heat value of one lb. of dry coal, per cent.,	59.8	62.8
	COST OF EVAPORATION.		
74.	Cost of coal per ton of 2000 lbs. delivered in boiler room, $	.95	.95
75.	Cost of fuel for evaporating 1,000 lbs. of water under observed conditions, $	.09	.080
76.	Cost of fuel used for evaporating 1,000 lbs. of water from and at 212 degrees, $	.077	.072
	SMOKE OBSERVATIONS.		
77.	Percentage of smoke as observed, per cent.,		
78.	Weight of soot per hour obtained from smoke meter, ounces,		
79.	Volume of soot per hour obtained from smoke meter, cub. in.		
	METHODS OF FIRING.		
80.	Kind of firing (spreading, alternate, or coking).		
81.	Average thickness of fire.	5"	5"
82.	Average intervals between firing for each furnace during time when fires are in normal condition.		
83.	Average interval between times of leveling or breaking up.		
	ANALYSIS OF THE DRY GASES.		
84.	Carbon dioxide (CO_2), per cent.,	8.40	8.36
85.	Oxygen (O), per cent.,	10.1	10.01
86.	Carbon monoxide (CO), per cent.,	.16	.23
87.	Hydrogen and hydrocarbons, per cent.,		
88.	Nitrogen (by difference) (N), per cent.,	81.26	81.40

HEAT BALANCE, OR DISTRIBUTION OF THE HEATING VALUE OF THE COMBUSTIBLE.

Total Heat Value of 1 lb. of Combustible, B.T.U.

No.	Item	B.T.U.	Per Cent.	B.T.U.	Per Cent.	B.T.U.	Per Cent.	B.T.U.	Per Cent.
1.	Heat absorbed by the boiler = evaporation from and at 212 degrees per pound of combustible × 965.7.								
2.	Loss due to moisture in coal = per cent. of moisture referred to combustible ÷ 100 × [(212 − t) + 966 + 0.48 (T − 212)] (t = temperature of air in the boiler-room, T = that of the flue gases)								
3.	Loss due to moisture formed by the burning of hydrogen = per cent. of hydrogen to combustible ÷ 100 × 9 × [(212 − t) + 966 + 0.48 (T − 212)].								
4.	Loss due to heat carried away in the dry chimney gases = weight of gas per pound of combustible × 0.24 × (T − t).								
5.	Loss due to incomplete combustion of carbon = $\frac{CO}{CO_2 + CO} \times \frac{\text{per cent. C in combustible}}{100} \times 10{,}150$.								
6.	Loss due to unconsumed hydrogen and hydrocarbons, to heating the moisture in the air, to radiation, and unaccounted for. (Some of these losses may be separately itemized if data are obtained from which they may be calculated.)								
	Totals		100.00		100.00		100.00		100.00

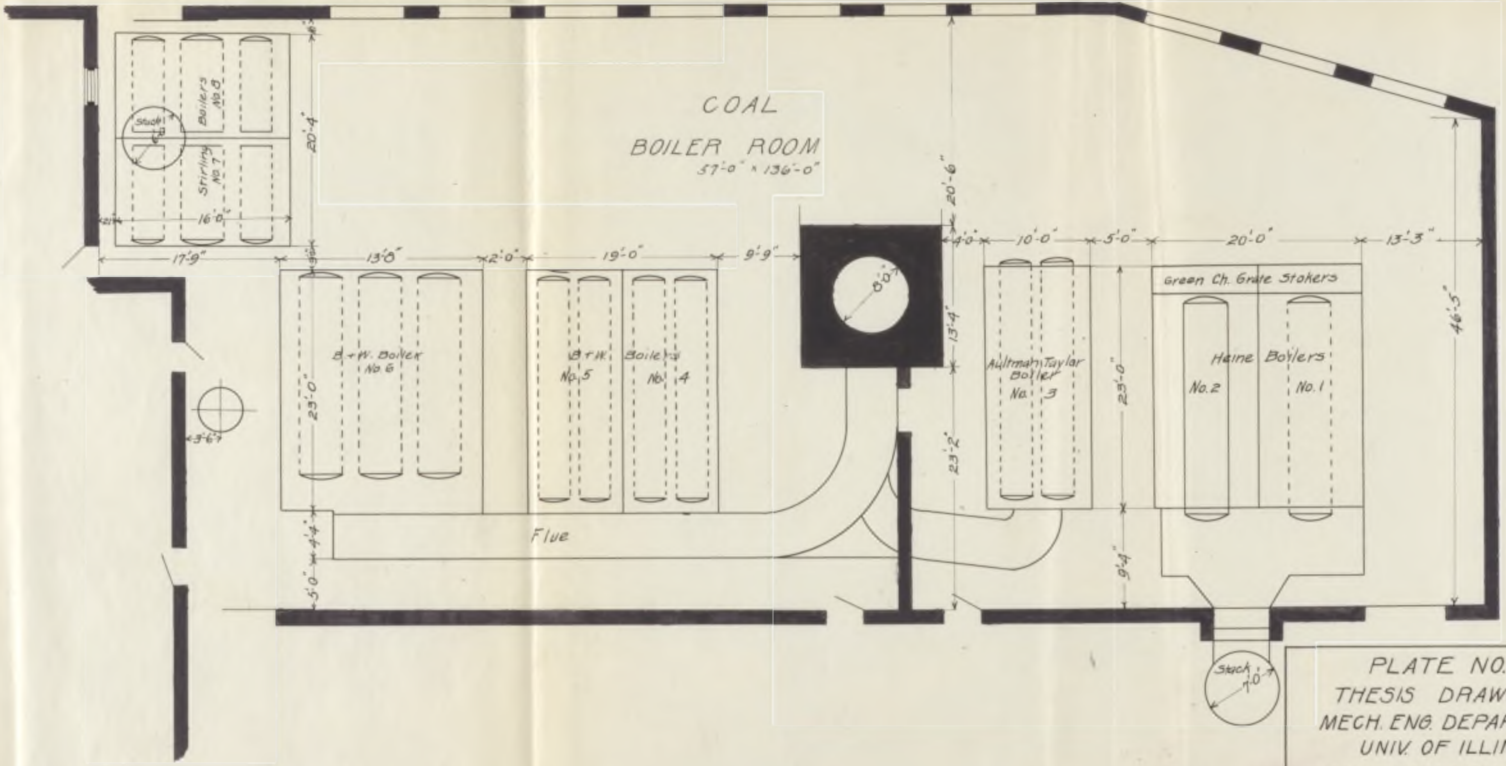


PLATE NO. I
THESIS DRAWING
MECH. ENG. DEPARTMENT
UNIV. OF ILLINOIS

PLAN OF BOILER ROOM

Scale $\frac{1}{8}$" = 1 ft. May 15. 1905

F. S. Hadfield

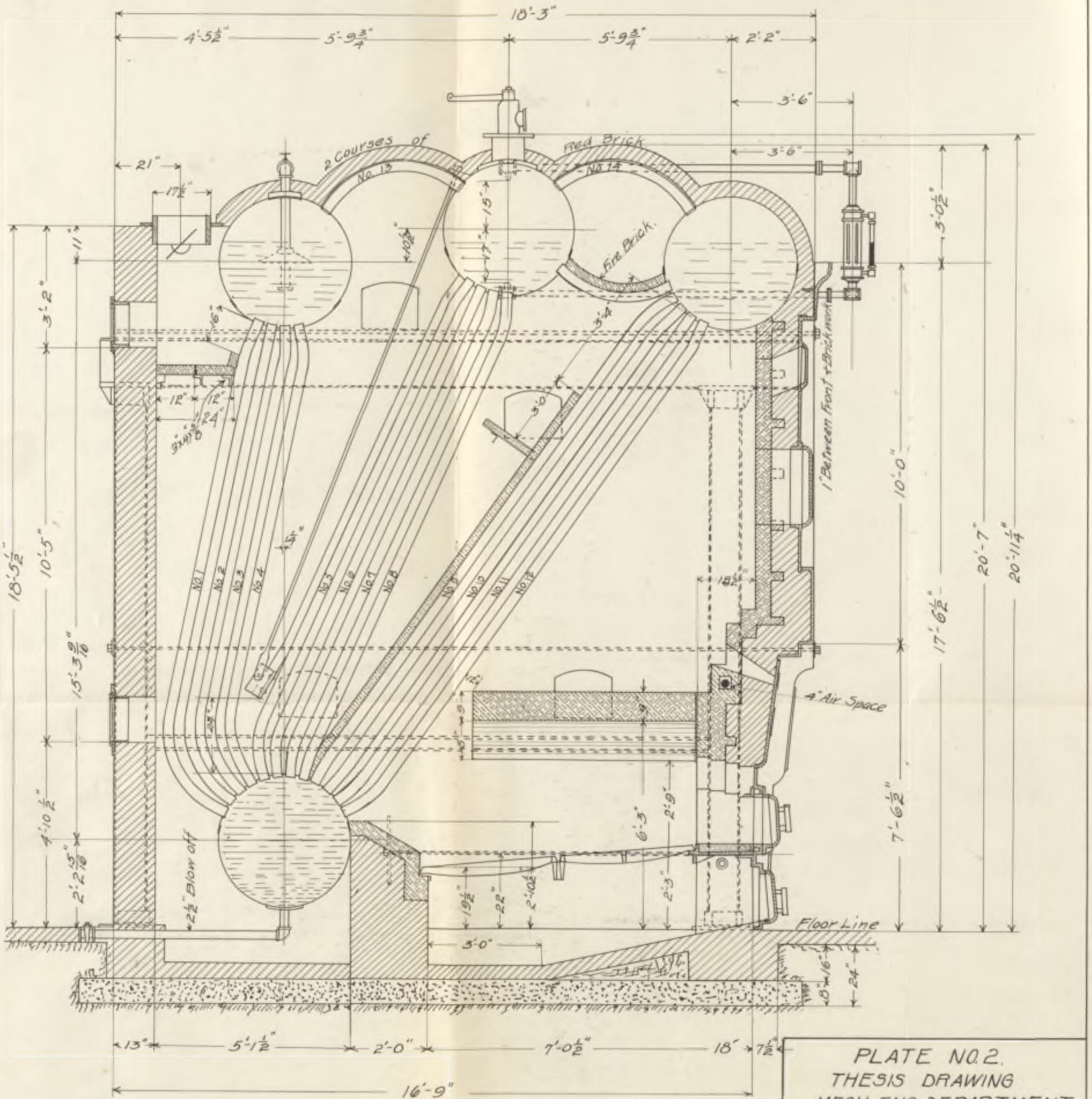
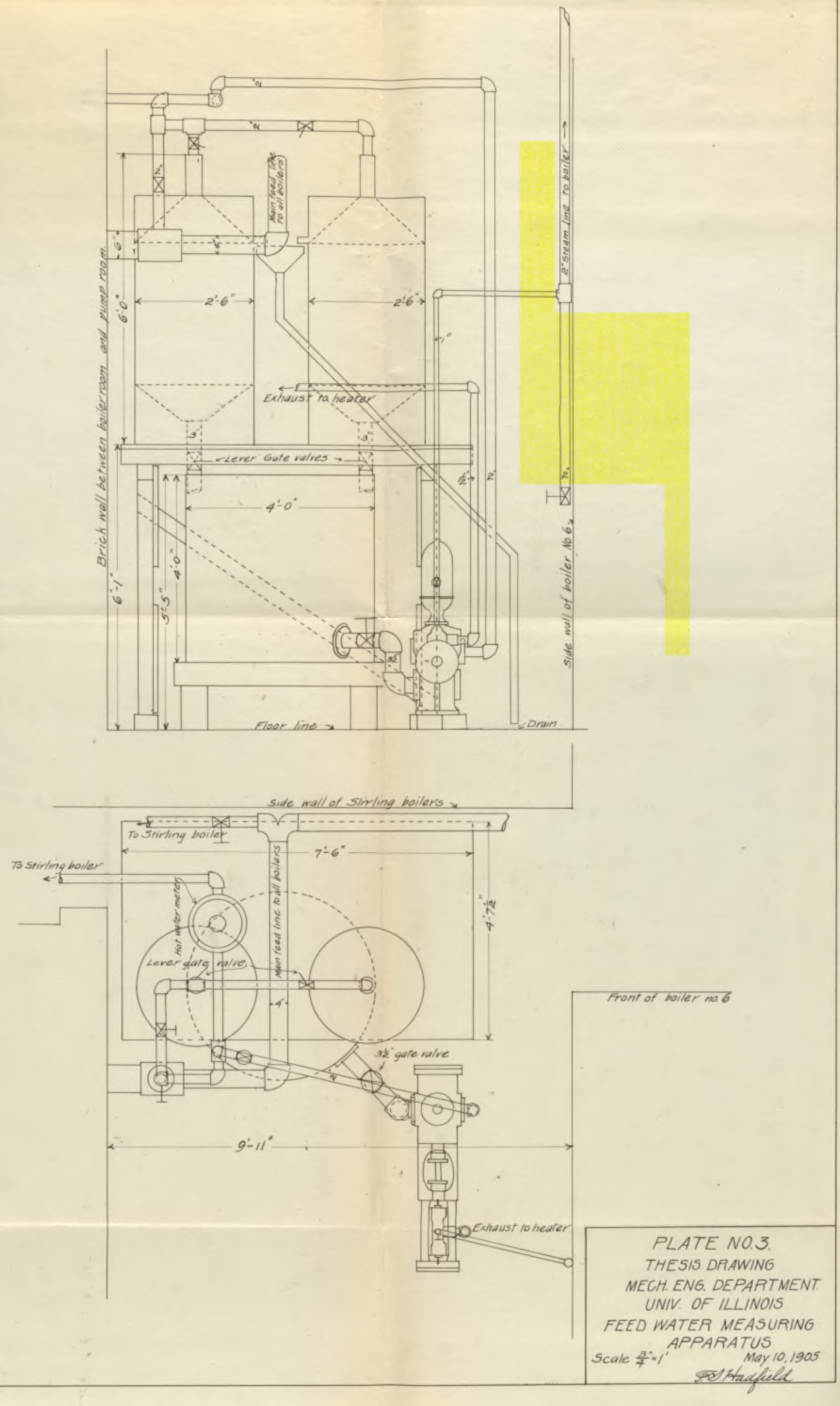


PLATE NO. 2.
THESIS DRAWING
MECH. ENG. DEPARTMENT
UNIV. OF ILLINOIS
CROSS SECTION OF
STIRLING BOILER
Scale ½" = 1 ft.
May 12, 1905.
F. J. Hadfield


2" steam line to boiler
Main feed line to all boilers
Brick wall between boiler room and pump room
6'-0"
6"
2'-6"
2'-6"
1"
Exhaust to heater
Lever Gate valves
4'-0"
4'-0"
5'-5"
6'-1"
Side wall of boiler No 6
Floor line
Drain
Side wall of Stirling boilers
To Stirling boiler
To Stirling boiler
7'-6"
Hot water meter
Lever gate valve
Main feed line to all boilers
4'-7½"
4"
Front of boiler no. 6
3½" gate valve
9'-11"
Exhaust to heater
PLATE NO.3.
THESIS DRAWING
MECH. ENG. DEPARTMENT
UNIV. OF ILLINOIS
FEED WATER MEASURING
APPARATUS
Scale ¾"=1'
May 10, 1905
F.S. Hadfield

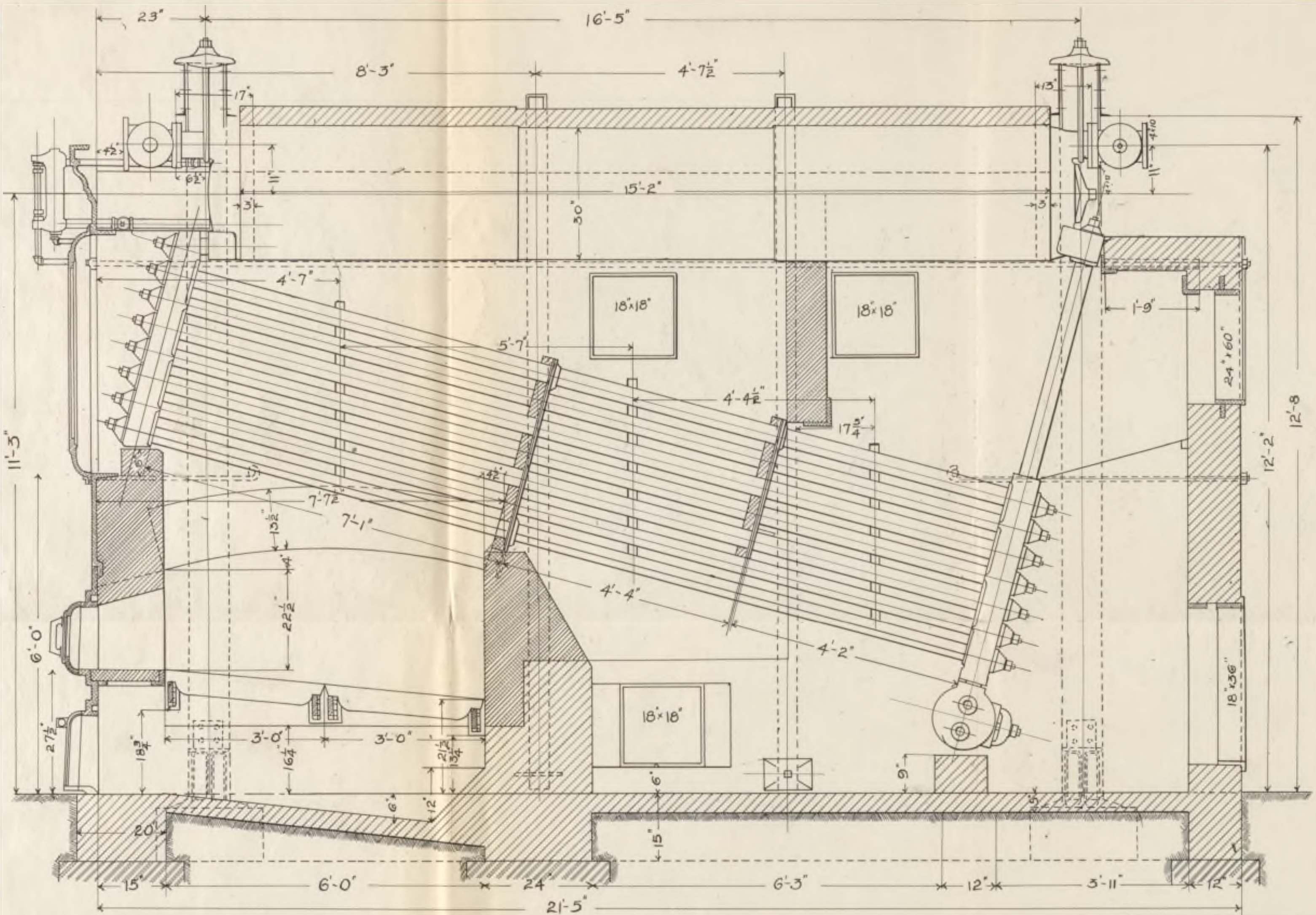


PLATE NO. 4
THESIS DRAWING
MECH. ENG. DEPARTMENT
UNIV. OF ILLINOIS
LONGITUDINAL SECTION OF
BABCOCK & WILCOX BOILER
Scale ¾" = 1 ft.
May 10, 1905
F. S. Hadfield

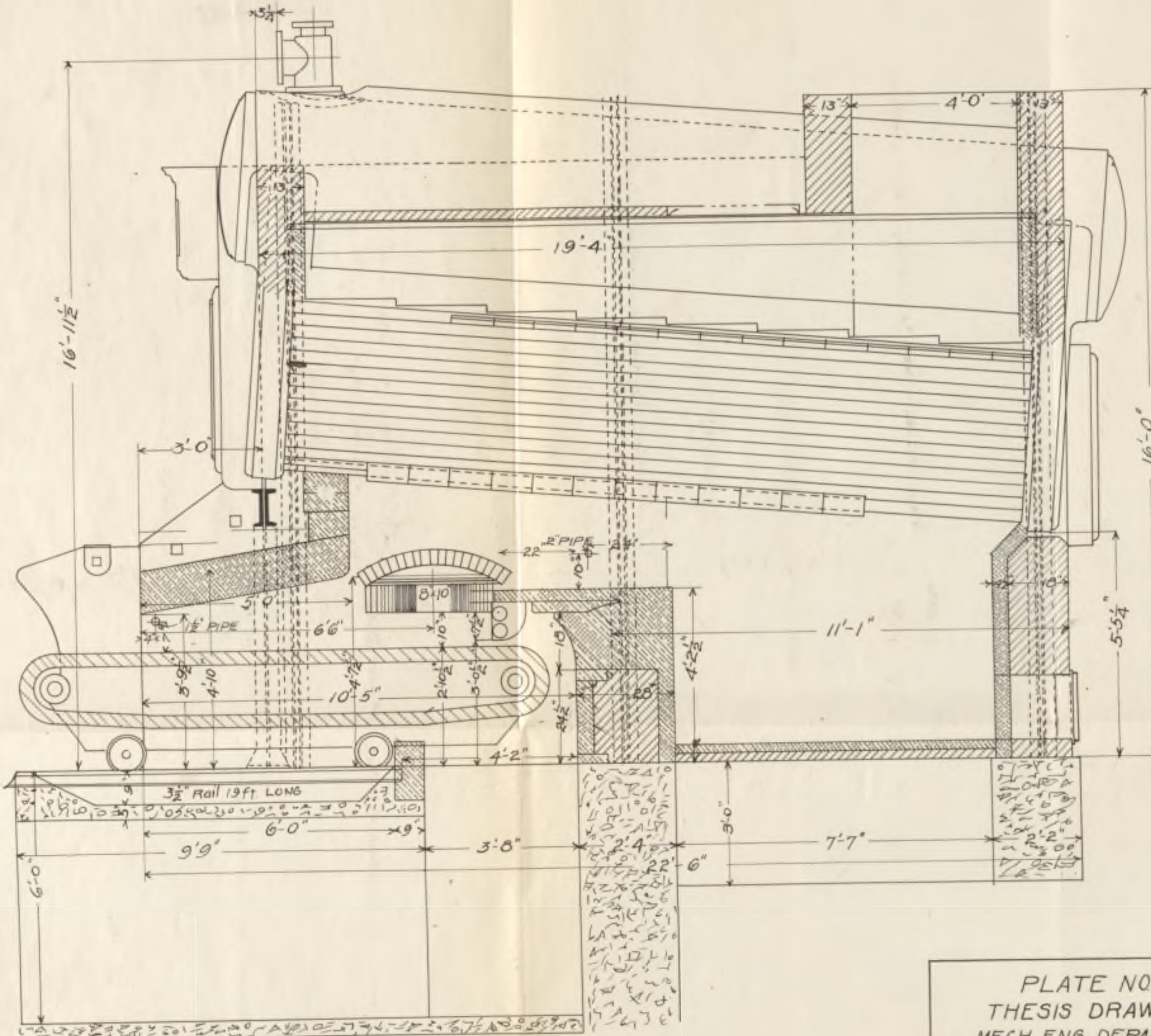


PLATE NO.5.
THESIS DRAWING
MECH. ENG. DEPARTMENT
UNIV. OF ILLINOIS.
LONGITUDINAL SECTION
OF HEINE BOILER
Scale ½" = 1 ft May 2, 1905
F. S. Hadfield